Raman amplifier system

The invention is based on a priority application EP 03290956.6 which is hereby incorporated by reference.

Field of the invention.

The present invention relates to the field of Raman amplifiers capable of being used for amplification of optical signals in various optical communication systems and a Raman amplification method.

Background and prior art

The principle of Raman optical amplification is as such known from the prior art. Raman amplifiers utilise stimulated Raman scatterings to create optical gain. A typical Raman amplifier system includes a high-power pump laser and a directional coupler. The optical amplification occurs in the transmission fibre itself, distributed along the transmission path of the optical signal. As optical fibres consist of amorphous silicon a spectrum of Raman scattering is provided such that the whole spectrum used in the WDM system is amplified as well as the noise using a single wavelength pump. The gain spectrum as well as the fibre losses result in a non-equal power of the individual channels, which requires some sort of successive gain-flattening, for example by means of variable optical attenuators.

A high-power pumping unit for a Raman system is known from Yoshihiro Emori and Shu Namiki, 'Demonstration of Broadband Raman Amplifiers: a Promising Application of High-power Pumping Unit', Furukawa review, number 19, 2000.

Further, usage of silicon-on-insulator (SOI) instead of an optical fibre has been published (R. Claps et al, '*Stimulate Raman scattering in silicon waveguides'*, Electronics Letters, vol. 38 No. 22, October 2002, and R. Claps et el '*Observation of Raman emission in silicon waveguides at 1.54 μm* ', Optics Express, vol. 10, No. 22 November 2002).

Summary of the invention

The present invention provides for an improved Raman amplifier system using a crystalline material as an optical waveguide. This is based on the discovery that crystalline materials have a well defined Raman wavelength shift rather than a spectrum of Raman wavelength shift as it is the case for optical fibres consisting of amorphous silicon which are used in prior art Raman amplifier systems. Usage of a crystalline material enables to concentrate the Raman amplification effect to a specific optical wavelength which reduces the required interaction length of the pump light and the optical signal to be amplified and also prevents the amplification of noise.

In accordance with a preferred embodiment of the invention a semiconductor is used as a waveguide material. Preferably semiconductors from group IV, II-VI or III-V are used, such as indium-phosphite, gallium-arsenite, silicon-germanium.

In accordance with a further preferred embodiment of the invention the optical waveguide is provided by a semiconductor-on-insulator structure, such as a silicon-on-insulator (SOI) structure. Usage of such a structure has the advantage that state of the art semiconductor fabrication methods can be used for fabrication of the wave guide and that the required interaction length of the optical signal to be amplified and the pump light can be further reduced to the order of 1 cm which enables fabrication of the Raman amplifer system as an integrated circuit chip.

In accordance with a further preferred embodiment of the invention the optical waveguide is provided by a membrane of a semiconductor layer. Usage of such

a structure has the advantage that the confinement of the optical mode is enhanced as the refractive index contrast of the surrounding air-cladding is higher. This further reduces the interaction length of the system.

In accordance with a further preferred embodiment of the invention the optical waveguide is provided by a defect waveguide in a photonic crystal. Usage of such a structure has the advantage that the confinement of the optical mode can be enhanced due to the photonic bandgap of the surrounding material. The enhanced confinement can be vertical, lateral or both. This further reduces the interaction length of the system.

In accordance with a further preferred embodiment of the invention isotopically purified crystalline material, such as an isotopically purified semiconductor is used for the optical waveguide. Isotopically purified semiconductors are as such known from the prior art (cf. Steven J. Bunden, '*High thermal conductivity silicon*', semiconductor fabtech 13th edition, page 297). Usage of isotopically purified crystalline material in accordance with the present invention is based on the discovery that different isotopes of the same element have slightly different Raman wavelength shifts. Using isotopically purified crystalline material for the optical waveguide of the Raman system has thus the advantage that the Raman wavelength shift is determined with even greater precision. This further concentrates the Raman amplification effect to the desired wavelength and enables to further reduce the interaction length of the pump light and the optical signal to be amplified.

In accordance with a further preferred embodiment of the invention separate laser pumps are provided for a plurality of optical signals having different wavelengths (a WDM system). The wavelengths of the laser pumps precisely match the wavelengths of the optical signals to be amplified minus the Raman wavelength shift of the crystalline material of the optical wave guide. This enables to precisely control the amplification of each individual optical signal and makes usage of variable optical attenuators redundant.

Brief description of the drawings

In the following a preferred embodiment of the invention will be described in greater detail by making reference to the drawing in which Figure 1 shows a block diagram of a Raman amplifier system with a semiconductor-on-insulator optical waveguide.

Detailed description

Figure 1 shows Raman amplifier system 100 which comprises an optical waveguide 102 and laser 104. In the preferred embodiment considered here optical waveguide 102 is a semiconductor-on-insulator waveguide. For example rib-like waveguide layer 106 consists of crystalline silicon and is located on insulator 108, such as silicon dioxide (SiO_2). For example the width 110 of waveguide layer 106 is between 0.5 μm to 10 μm, height 112 is between 1 μm and 10 μm, and height 114 is between 0.25 μm and 7 μm. Preferably the semiconductor material of waveguide layer 106 is isotopically purified for greater precision of the Raman amplification.

Laser 104 serves as a source of pump light which is coupled into optical waveguide 102 for amplification of an optical signal which propagates through optical waveguide 102.

When the semiconductor material which constitutes waveguide layer 106 has a Raman wavelength shift of $\Delta\lambda$ and the optical signal propagating through waveguide layer 106 has a wavelength of λ_1, a wavelength of λ_2 is selected for laser 104, where $\lambda_2 = \lambda_1 - \Delta\lambda$.

When there are multiple optical signals propagating through optical waveguide 102, there needs to be a corresponding number of sources for pump light at the corresponding wavelengths. For example if there is an additional optical signal having a wavelength λ_3 there needs to be an additional source for pump light having a wavelength of $\lambda_4 = \lambda_3 - \Delta\lambda$.

It is a particular advantage of Raman amplifier system 100 that it can be implemented on a single integrated circuit chip with an interaction length of e.g.

0.25cm to 1cm. The length of optical waveguide 102 can even be shorter especially if isotopically purified semiconductor material is used for waveguide layer 106.

List of Reference Numerals

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100	Raman amplifier system
102	optical waveguide
104	laser
106	waveguide layer
108	insulator
110	width
112	height
114	height